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Oct. 16, 1992

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Coherent Anti-Stokes Raman Spectroscopy of Highly
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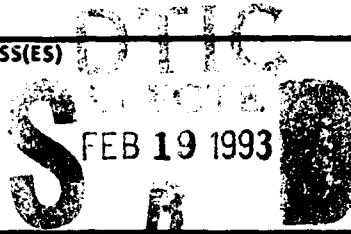
5. FUNDING NUMBERS

DAAL03-88-K-0114

6. AUTHOR(S)

Eric Mazur

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Harvard University
Division of Applied Sciences
29 Oxford Street
Cambridge, MA 021388. PERFORMING ORGANIZATION
REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

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ARO 25653.4-PH

11. SUPPLEMENTARY NOTES

The view, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The thrust of this project was to study the vibrational dynamics of infrared multiphoton excited (IRMPE) molecules in a free supersonic jet expansion using time-resolved broadband coherent anti-Stokes Raman spectroscopy (CARS). The work carried out is an extension of work previously carried out under ARO contract DAAG29-85-K-0060 which expired in February 1988.

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Coherent anti-Stokes Raman spectroscopy of Highly Vibrationally Excited Molecules

Final Report

Eric Mazur

October 16, 1992

U.S. Army Research Office

DAAL03-88-K-0114

Harvard University

Approved for public release;
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25653-PH

FINAL REPORT

- 1 ARO PROPOSAL NUMBER: 25653-PH
2. PERIOD COVERED BY REPORT: 15 July 1988 – 14 July 1992
3. TITLE OF PROPOSAL: *Coherent anti-Stokes Raman spectroscopy of Highly Vibrationally Excited Molecules*
4. CONTRACT OR GRANT NUMBER: DAAL03-88-K-0114
5. NAME OF INSTITUTION: Harvard University
6. AUTHOR OF REPORT: Eric Mazur
7. LIST OF MANUSCRIPTS SUBMITTED OR PUBLISHED UNDER ARO SPONSORSHIP DURING THIS REPORTING PERIOD, INCLUDING JOURNAL REFERENCES:
 - a. "Energy localization in infrared multiphoton excited CF_2Cl_2 studied by time resolved Raman spectroscopy," Jyhpyng Wang, Kuei-Hsien Chen and Eric Mazur, Int. Conf. Quantum Electronics 1988, Tokyo Japan, Techn. Digest, 496
 - b. "Can chemical reactions be controlled with picosecond infrared pulses?", Eric Mazur, J. Electr. Chem. Soc. 35:C386 (1988)
 - c. "Multiplex coherent anti-Stokes Raman spectroscopy study of infrared-multiphoton-excited OCS," Kuei-Hsien Chen, Cheng-Zai Lü, Luis A. Avilés, Eric Mazur, Nicolaas Bloembergen and M.J. Shultz, J. Chem. Phys., 91 (3) (1989) 1462
 - d. "Multiplex CARS Study of Infrared-Multiphoton-Excited OCS," Kuei-Hsien Chen, Cheng-Zai Lü, Eric Mazur, Nicolaas Bloembergen and M.J. Shultz, to appear in Laser Spectroscopy, Ed. M. Feld (Plenum, 1989), 439
 - e. Collisional and intramolecular dynamics of low-lying vibrational states of infrared multiphoton excited molecules, Eric Mazur, Cheng-Zai Lü, Shrenik Deliwala and Jay Goldman, Tech. Digest. XVII Int. Conf. on Quantum Electronics 8 (1990) 214.
 - f. Coherent anti-Stokes Raman spectroscopy of highly vibrationally excited molecules in a jet, Eric Mazur, Cheng-Zai Lü, Shrenik Deliwala, Jay Goldman, Proc. XII Int. Conf. Raman. Spectr. (Wiley, New York) 232.
 - g. Nonlinear spectroscopy of infrared multiphoton excited molecules, Eric Mazur and Cheng-Zai Lü, in Resonances, a volume in honor of the 70th birthday of Nicolaas Bloembergen, Eds. M. Levenson, E. Mazur, P. Pershan and Y.R. Shen (World Scientific, Singapore, 1990) 165.
 - h. Direct evidence for n_1 -mode excitation in the infrared multiphoton excitation of SO_2 , Cheng-Zai Lü, Jay Goldman, Shrenik Deliwala, Kuei-Hsien Chen and Eric Mazur, Chem.

Phys. Lett, 176 (1991) 335.

- i. Kuei-Hsien Chen, Cheng-Zai Lü, Nicolaas Bloembergen, and Eric Mazur, J. Raman Spectroscopy, 21 (1990) 819.
- j. Time-resolved spectroscopy of vibrational energy transfer in infrared multiphoton excited SF₆, S. Deliwala, J. Goldman, K.H. Chen, C.Z. Lü and E. Mazur, in preparation.
- k. Coherent anti-Stokes Raman spectroscopy of infrared multiphoton excited molecules, K.H. Chen, C.Z. Lü, J. Goldman, S. Deliwala, and E. Mazur, in preparation.

8. SCIENTIFIC PERSONNEL SUPPORTED BY THIS PROJECT AND DEGREES AWARDED DURING THIS REPORTING PERIOD:

Prof. Eric Mazur	—	half period
Mr. K.H. Chen	—	half period
Mr. S. Deliwala	—	half period
Mr. J. Goldman	—	summer
Mr. J. Wang	—	quarter period

Mr. J. Wang was awarded the Ph.D. degree in September 1988 on a thesis entitled "Intramolecular energy distribution of infrared multiphoton excited molecules". After a two-year postdoc at MIT he has accepted a faculty position in Taiwan.

Mr. K.H. Chen obtained the Ph.D. degree in September 1989 on a thesis entitled "Coherent anti-Stokes Raman spectroscopy of highly vibrationally excited molecules". He is currently holding a position at General Electric.

9. REPORT OF INVENTIONS (BY TITLE ONLY): None

Eric Mazur
Department of Physics
Harvard University
Cambridge, MA 02138

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FINAL REPORT

1. The thrust of this project was to study the vibrational dynamics of infrared multiphoton excited (IRMPE) molecules in a free supersonic jet expansion using time-resolved broadband coherent anti-Stokes Raman spectroscopy (CARS). The work carried out is an extension of work previously carried out under ARO contract DAAG29-85-K-0060 which expired in February 1988.

With the funds allocated under this contract we have *a)* obtained detailed information on the infrared multiphoton excitation in OCS, SO₂, ethylene (C₂H₄) and SF₆, *b)* built a supersonic molecular beam apparatus, and *c)* developed laser and UHV equipment for a new phase in our research program. See points 2-4 below for more information.

2. As originally planned we studied the dynamics of highly vibrationally excited molecules. Below is a brief summary of research findings for each of the molecular systems studied.

OCS. The OCS molecule has three vibrational degrees of freedom. The overtone of the ν_2 mode at 527 cm⁻¹ can be pumped by the CO₂ laser. Because of the cross-anharmonicity of the two modes, the population in the ν_2 mode can be monitored by observing the coherent anti-Stokes signal from the ν_1 mode at 859 cm⁻¹. In bulk OCS it was found that after excitation with 100-ns CO₂ laser pulses the distribution within the ν_2 ladder is nearly equilibrium at all but the highest excitation. In fact, even though the laser only populates the first overtone level ($\nu = 2$), the distribution equilibrates extremely rapidly because of collisions. This rapid equilibration only occurs mostly within the ν_2 ladder — very little transfer of energy to other modes (e.g. the ν_1 mode) is observed. Thus, OCS provides a convenient way to study the interaction of a nearly isolated anharmonic oscillator with monochromatic infrared photons. In the bulk the excitation is mostly collisional. From the time-dependence of the peak intensities in the CARS spectrum we were able to determine the collisional relaxation of the energy in the ν_2 mode.

SO₂. The study of infrared multiphoton excitation of small polyatomic molecules such as SO₂ has received considerable attention in the literature. This molecule is representative of small size

systems which, according to the quasicontinuum model, can be difficult to excite to high vibrational levels since the density of states at low excitation is relatively small. While observation of inverse electronic excitation in SO_2 clearly demonstrated that infrared multiphoton excitation to high vibrational levels is possible, these studies left unresolved the issue of which mode of the molecule is actually excited by the CO_2 -laser. The ambiguity arises primarily because there is no available CO_2 -laser line resonant to the ν_1 -mode. The 9R(32) line is a strong CO_2 -laser line close to ν_1 -mode resonance; the 9P(32) line, on the other hand, is resonant with the first overtone of the ν_2 -mode; and the 9R(22) line, one of the more intense CO_2 lines in the 9- μm region, lies between these two bands (71 cm^{-1} detuned from ν_1 and 44 cm^{-1} from $2\nu_2$). Because infrared multiphoton excitation is intensity dependent for a small molecule like SO_2 , the strong 9R(22) line is historically the one most often utilized in the literature. It is not immediately clear, however, whether the ν_1 stretching mode or the $2\nu_2$ overtone band undergoes infrared multiphoton excitation when this line is used.

Using the time-resolved CARS setup we are able to directly observe the vibrational population in the various modes of the molecule. We determined that the ν_1 -mode is excited, and that no detectable overtone pumping occurred under a large number of conditions, including tuning to the 9R(32), the 9P(32), and the 9R(22) CO_2 -laser lines, samples in a static gas cell or a supersonic jet, and energy fluxes up to 3 J/cm^2 .

It should be emphasized that our results show that both 9R(22) and 9R(32) pumping of SO_2 leads to excitation of the ν_1 -mode at 1151.3 cm^{-1} . While these lines are significantly detuned from the band head, they fall near the peak of the rotational Q -branch of the ν_1 -mode at room temperature. This result should provide a clearer understanding of previous and future work in the field, and also illustrates the utility of the multiplex BOXCARS technique for direct observation of mode-selective excitation.

C₂H₄. Rotational CARS investigations of IRMPE excited ethylene revealed a richly complex structure which was complicated by the fact that CO_2 -laser pumping directly populated the probe mode. Although we were able to observe several line dependencies on IR excitation, we discontinued our efforts on this molecule — it appears to be too complex to model or understand in sufficient detail at this time. Possible future investigations of this system should probably incorporate simultaneous rotational and vibrational spectroscopy, so that the complete state of the system can be identified.

*SF*₆. Detailed investigation of IRMPE in *SF*₆ has settled some important issues. We first probed the *SF*₆ molecules in a pulsed supersonic expansion jet at variable distances from the nozzle to achieve between 10 and 10⁻² collisions per 100 ns (the time scale of the pump-probe delay). Spectra with variable pump-probe delays were time resolved on a Hamamatsu C1953 streak camera. Near the nozzle we observed extremely rapid redistribution of energy of low lying states due to frequent collisions with molecules excited to the quasicontinuum. Farther from the nozzle, reduced collisions allow longer observation of nonequilibrium excited low-level states. This allows us to gain new quantitative detail about multiphoton excitation near the quasicontinuum threshold and sheds new light on the interpretation of results from previous researchers in the field. We then performed a second experiment in which the collision rate was varied by adding a buffer gas of either Argon or Helium to reduce collisions between *SF*₆ molecules. As expected we observed a qualitatively similar dependence of the molecular dynamics on the collision rate in the two experiments.

Using a specially developed computer simulation program developed during this contract period, we have been able to conclusively show that a multi-temperature distribution is produced by the infrared excitation of the *SF*₆ molecules. We are able to approximate this distribution with a two-temperature model, and thus observe the evolution of two temperatures as we change experimental parameters such as collision rate or pump-probe delay. It has become clear that it is collisions, not intramolecular vibrational relaxation, that dominate the dynamics of energy transfer from the laser-pumped mode to non-pumped modes. Analysis of the data yield approximate vibrational state populations of the excited molecular ensemble as a function of time. Interestingly, we find a non-thermal distribution of energy in a laser pumped mode which persists for up to 400 ns after excitation — a time much longer than any intramolecular relaxation time scale. Measurement of the relative excitation in the pump and heat bath modes as a function of delay time and collision rate suggests that intramolecular vibrational relaxation may actually be much slower than previously expected. This important finding may in part account for the wide disparity of previous results in this type of experiments.

3. *Supersonic molecular beam apparatus.* With funds from this contract we developed and built a supersonic molecular beam apparatus. The adiabatic cooling of the molecules in the beam expansion has two effects: *a*) the collisional rate of the molecules is greatly reduced because of the translational cooling, and *b*) far fewer rotational and vibrational states are populated, greatly

simplifying the analysis of the data. Pure rotational CARS spectra of N_2 in the beam show that at a distance of 20 mm from the nozzle the rotational temperature is reduced to below 5 K. At this temperature only the $J = 0$ and $J = 1$ states are significantly populated. Similar low temperatures have been observed for other molecules.

4. *Preparation for future work.* During a final no-cost extension period of this contract, which served as a bridge until a new contract was obtained, we terminated the current research effort on nanosecond nonlinear spectroscopy of highly excited molecules and made preparations for our experimental goals in the next three-year contract period. We intend to utilize the expertise of our group in nonlinear spectroscopy and surface, molecular and interface physics to study a variety of ultrafast dynamical systems. With molecules, we hope to extend the pioneering work of Zewail and Sorokin in molecular photoexcitation. In particular we plan to investigate molecular clusters and monolayers adsorbed on surfaces. This requires on one hand a new tunable femtosecond laser system and an ultrahigh vacuum chamber. Construction of both of these pieces of equipment is nearly complete.

Ti:sapphire laser development. The laser requirements for the planned research are a highly stable, sub-100-fs pulse oscillator which is broadly wavelength tunable. To this end we have designed and built a self mode-locked Ti:Sapphire laser with high quality, stable optical mounts and components, using a HITCI dye-jet saturable absorber and SF14 prism pair which provides a very stable 100-MHz mode-locked train of 100-fs pulses. We can obtain powers up to 1W of near-TEM₀₀ output in a range tunable from 700 to 900 nm with a birefringent tuning plate and a single set of optics, and a peak slope efficiency of 7% around 800 nm. We have also observed self mode-locking without the saturable absorber jet, which produced ps pulses. We expect soon to complete construction of a 10-Hz Nd:YAG laser pumped multipass Ti:Sapphire amplifier. Pending the availability of funding for a new pump-laser, we are also considering at least two possible new designs at this time for a high-repetition rate (>1 kHz) Ti:Sapphire amplifier.

UHV chamber development. Our sample chamber requirements are unusual for a UHV apparatus. We need a UHV (10^{-11} torr) surface science chamber that allows sample preparation and characterization; however we also require wide angle optical access to the sample with small distances between the sample and the chamber windows, precise multi-axis translational and angular sample positioning, low temperature (10-70 K) cooling, and extremely high

resistance to sample vibration. After visiting several other research labs which have designed chambers for similar purposes, Dr. W. Mieher has designed a two level system which should satisfy all our needs. An upper surface science level will contain ion guns and gas dosers for sample preparation, and LEED/Auger and mass spectrometry for sample characterization. Additional ports on this level will allow optical experiments to be performed simultaneously with surface science probes if desired, plus possible future addition of a load lock for sample changes without breaking vacuum. The lower level will be a small six inch cube with windows on four sides, which allows excellent wide angle, multiplanar optical access to the sample. The sample will be positioned by a large bore vertical manipulator which can be filled with LN₂ or LHe for direct sample cooling, and which can be solidly gripped from side ports to provide precise repeatable sample positioning and high vibrational stability. Pumping will be provided by a turbo pump on the upper level and an ion pump with a LN₂-cooled Ti sublimator below the system. Construction of this system is well underway and we expect to begin experimenting with samples in UHV by the end of the year.

5. *Other achievements.* Another noteworthy achievement is that the principal investigator of this contract, Prof. Eric Mazur, obtained tenure at Harvard during this contract period. He was also elected Fellow of the American Physical Society. Two of the graduate students involved in the project obtained their Ph.D. degree.

EQUIPMENT PURCHASES

All transactions on this grant were charged to Harvard account 44-935-7237-2-30. A complete list of equipment purchases for this account, listing vendors, items purchased and purchase price, is attached.

44-935-7237-30

Period: 07/01/1988-09/30/1992

Report Date: 16 Oct 92

Orderer: ERIC MAZUR

Comm. or Trxn Date	Class	PO #	Vendor	Spent	Committed
10/11/90	12	29813	COHERENT RADIATION	28,333.71	
		1	INNOVA 200-10 ARGON ION LASER SYSTEM WITH 6 MONTHS OR 750 HOUR SERVICE AGREEMENT QUOTE #3361		
		1	INNOVA 200-10 ARGON ION LASER SYSTEM WITH 6 MONTHS OR 750 HOUR SERVICE AGREEMENT QUOTE #3361		
			Total EQUIPMENT	28,333.71	.00
06/27/89	13	24687	GENIGRAPHICS	195.00	
		15	SLIDES		
			Total SUPPLIES PRINT & STA	195.00	.00
10/02/89	20	24126	AMERICAN INSTITUTE OF PHYSI	335.00	
		/	CODE 19. ARTICLE "MULTIPLEX COHERENT ANTI-STOKES RAMAN SPECTROSCOPY STUDY OF INFRARED-MULTIPHOTON-EXCITED OCS" BY KUEI-HSIEN CHEN, CHENG-ZAI LU, LUIS AVILES, ERIC MAZUR, NICOLAS BLOEMBERGEN AND MARY J. SHULTZ. TENTATIVE SCHEDULED ISSUE DATE AUG 1, 1989		
		250	REPRINTS W/O COVERS OF ABOVE		
		1	ARTICLE CHARGE		
			Total PUBLISHING	335.00	.00
10/02/89	90	24126	AMERICAN INSTITUTE OF PHYSI	30.00	
			Total REPRINTS	30.00	.00
			Total for Orderer: ERIC MAZUR	28,893.71	.00

44-935-7237-30

Period: 07/01/1988-09/30/1992

Report Date: 16 Oct 92

Orderer: J GOLDMAN

Ordn. or rxn Date	Class	PO #	Vendor	Spent	Committed
1/01/89	12	25943	QUANTEL INTERNATIONAL	190.00	
		2	CG ION 3 DI FILTER FOR Y6471C LASEK		
			Total EQUIPMENT	190.00	.00
0/26/89	13	26099	VARIAN ASSOCIATES INC	149.44	
		1	0571-K24 IONIZATION GAUGE TUBE W/ 2-3/4" CONFLAT FLANGE		
			Total SUPPLIES PRINT & STA	149.44	.00
9/15/89	72	25566	HAMAMATSU CORP	205.34	
		1	REPAIR OF C1989 DISK DRIVE UNIT FOR STREAK CAMERA. DRIVE B NON-OPERATIONAL		
		1	C1989 DISK DRIVE UNIT FOR STREAK CAMERA		
9/22/89	72	25567	TEKTRONIX. INC.	354.00	
		1	REPAIR & CALIBRATE 7A24 DUAL PLUG-IN AMP S/N 8117970		
		1	REPAIR & CALIBRATE 7B80 TIME BASE PLUG-IN S/N B062241		
09/22/89	72	25567	TEKTRONIX. INC.	269.00	
			Total EQUIPMENT REPAIRS/MAINT	828.34	.00
Total for Orderer: J GOLDMAN				1,167.78	.00

44-935-7237-30

Period: 07/01/1988-09/30/1992

Report Date: 16 Oct 92

Orderer: JAY GOLDMAN

Comm. or Trxn Date	Class	PO #	Vendor	Spent	Committed
04/02/91	12	32211	KLINGER SCIENTIFIC	1,342.16	
		2	338070 MR80.25 TRANSLATION STAGE		
		2	338066 MR50.25 TRANSLATION STAGE		
		2	133102 P046 PRISM TABLE		
		2	133311 SK25.4 MIRROR MOUNT W/DIFFERENTIAL MICROMETER		
		2	338203B Pb5s BASE PLATE		
		3	338204B Pb8s BASE PLATE		
		2	338261 BR3 BRIDLES		
		2	338262 BR4 BRIDLES		
		2	080114 SCREWS M3X6		
		2	080136 SCREWS M4X6		
		1	080116 SCREWS M3X10		
		1	080118 SCREWS M4X10		
		1	080143 NUTS M3		
		1	080144 NUTS M3		
04/02/91	12	32211	KLINGER SCIENTIFIC	1,929.84	
04/02/91	12	32212	NEWPORT CORPORATION	1,284.00	
		1	XSD-24 2X4' BREADBOARD, DAMPED WITH MICROLOCK		
		1	LP-1B 5-AXIS GIMBAL MOUNT, 1" APERATURE WITH BASE		
		5	MFM-075 FLEXURE MIRROR MOUNT		
		5	MFM-B MOUNT BRACKET FOR FLEXURE MOUNT		
		1	RSA-1 ROTATION STAGE, 1" APERATURE		
		1	XSD-24 CREDIT AGAINST TABLE WITHOUT TIEDOWNS		
		1	XSD-24 REPLACEMENT TABLE WITH TIEDOWN SLOTS		
		1	TIEDOWNS		
07/16/91	12	32212	NEWPORT CORPORATION	1,211.00	
07/16/91	12	32212	NEWPORT CORPORATION	-1,269.57	
07/16/91	12	32212	NEWPORT CORPORATION	1,269.57	
			Total EQUIPMENT	5,767.00	.00
02/15/90	13	27289	MEDICAL TECHNICAL GASES INC	903.35	
		3	UN2187 CARBON DIOXIDE, COLEMAN		
		5	UN1046 HELIUM GAS, ULTRA HIGH PURITY		
		3	UN1066 NITROGEN HIGH PURITY		
		10	Cylinder Rental		
		1	CREDIT AGAINST LEASE BALANCE		
03/01/90	13	27289	MEDICAL TECHNICAL GASES INC	55.30	
03/20/90	13	27289	MEDICAL TECHNICAL GASES INC	43.45	
04/01/90	13	28019	CAMBRIDGE VALVE & FITTING	9.18	
		1	SS-500-6 SWAGELOCK UNION TUBE FITTING, STAINLESS STEEL		
			5-1/16" TUBE TO 1/4" TUBE		
04/20/90	13	27289	MEDICAL TECHNICAL GASES INC	39.50	
05/11/90	13	27289	MEDICAL TECHNICAL GASES INC	39.50	

Transaction Summary Report
 44-935-7237-30
 Period: 07/01/1988-09/30/1992
 Report Date: 16 Oct 92

Order: K.H. CHEN

Mo. or n Date	Class	PO #	Vendor	Spent	Committed
26/88	12	23001	ARROW/KIERLUFF		73.00
		1	638MB INTERNAL HARD DISK FOR MAC II		
		1	UNIMAC KIT & CABLES		
		1	UNIMAC 5.25		
			Total EQUIPMENT	.00	73.00
06/88	47	23001	ARROW ELECTRONICS INC.	2,533.26	
19/88	47	23116	KINETICS INC	403.70	
		1	ETHERPORT II FOR MAC II		
		1	HOSTACCESS SOFTWARE		
27/88	47	23001	ARROW ELECTRONICS INC	78.26	
		1	638MB INTERNAL HARD DISK FOR MAC II		
		1	UNIMAC KIT & CABLES		
		1	UNIMAC 5.25		
02/89	47	23116	KINETICS INC	97.94	
		1	ETHERPORT II FOR MAC II		
		1	HOSTACCESS SOFTWARE		
			Total COMPUTER EQUIPMENT	3,113.16	.00
			Total for Orderer: K.H. CHEN	3,113.16	73.00

44-935-7237-30

Period: 07/01/1988-09/30/1992

Report Date: 16 Oct 92

er: KUEI HSIEN CHEN

mm. or	n Date	Class	PO #	Vendor	Spent	Committed
09/89	12	24448	4	SPECTRUM ENGINEERING INC. OMM1MX8- 1 MEG X 8. 100 uS. HIGH PROFILE RAM	684.50	
				Total EQUIPMENT	684.50	.00
12/89	13	23824	3	MEDICAL TECHNICAL GASES INC SIZE H CARBON DIOXIDE COLMAM GRADE	46.50	
			4	HELIUM GAS. 99.999% GRADE		
			3	UN1066 NITROGEN GAS. PREPURIFIED. 99.998%		
			218	Cyclinder rental		
12/89	13	23903	1	MATHESON GAS PRODUCTS SIZE 3 CARBONYL SULFIDE. 97.5% PURITY. 10 LBS	703.09	
			1	DEPOSIT ON ABOVE		
			1	SIZE 2L SULFUR DIOXIDE. 99.98% PURITY		
			1	DEPOSIT ON ABOVE		
12/89	13	23824	3	MEDICAL TECHNICAL GASES INC SIZE H CARBON DIOXIDE COLMAM GRADE	3.95	
			4	HELIUM GAS. 99.999% GRADE		
			3	UN1066 NITROGEN GAS. PREPURIFIED. 99.998%		
			218	Cyclinder rental		
12/89	13	23963	4	INSULATOR SEALS INC 9421010 ONE CONDUCTOR FEEDTHROUGH. 30 AMP. COPPER	83.00	
12/89	13	23824	3	MEDICAL TECHNICAL GASES INC SIZE H CARBON DIOXIDE COLMAM GRADE	579.35	
			4	HELIUM GAS. 99.999% GRADE		
			3	UN1066 NITROGEN GAS. PREPURIFIED. 99.998%		
			218	Cyclinder rental		
12/89	13	23824		MEDICAL TECHNICAL GASES INC	39.50	
12/89	13	23824		MEDICAL TECHNICAL GASES INC	31.60	
12/89	13	24517	5	MEDICAL TECHNICAL GASES INC GRADE H HELIUM 99.999%	512.50	
			12	CYCLINDER RENTAL		
12/89	13	23806	100	CAMBRIDGE VALVE & FITTING B-400 BRASS 1/4" SWAGELOK FERRULE LESS 7%	52.66	
			30	B-402-i BRASS 1/4" SWAGELOCK		
12/89	13	24517	5	MEDICAL TECHNICAL GASES INC GRADE H HELIUM 99.999%	19.75	
			12	CYCLINDER RENTAL		

44-935-7237-30

Period: 07/01/1988-09/30/1992

Report Date: 16 Oct 92

derer: LUIS AVILES

mm. or xn Date	Class	PO #	Vendor	Spent	Committed
/19/88	12	21659	UNIVERSITY OF LOWELL BOOKST	3,492.00	
		1	M5333 MAC II CPO		
		1	M0115 APPLE EXTENDED KEYBOARD		
		1	M0401 APPLE-COLOR HIGH-RES RGB MONITOR		
		1	M0213 4-BIT EXPANSION KIT		
		1	M5640 8-BIT VIDEO CARD		
/09/88	12	22336	Oriel Corporation	107.59	
		1	MODEL 58 SHORT PASS FILTER		
/26/89	12	22917	NEWPORT CORPORATION	216.00	
		4	KBX193 BICONVEX LENSES, FL = 30 CM, DIA = 3"		
/02/89	12	22986	VARIAN ASSOCIATES INC	51.34	
		2	953-5070 COOPER GASKETS, ID = 0.6", OD = 0.8"		
/06/89	12	22973	CVI LASER CORPORATION	548.00	
		2	DLM 55-1 TYPE I 45 DEGREE S DYE LASER MIRRORS		
/12/89	12	22751	UTILITIES SUPPLY	79.10	
		200	FG10 SEE CAT.#		
		2	000P8MT8 SEE CAT.#		
		2	000P8MC8 SEE CAT.#		
		2	000P8MC6 SEE CAT.#		
		2	000P8MC4 SEE CAT.#		
		2	000P8FC8 SEE CAT.#		
		2	COUPLING		
/01/89	12	23662	MINARIK ELECTRIC CO.	178.40	
		1	TYPE AA1 MINICOUNTER ROTATION #3, WITH TYPE A BASE MOUNT		
		1	TYPE AA1 MINICOUNTER ROTATION #4, WITH TYPE A BASE MOUNT		
			Total EQUIPMENT	4,672.43	.00
/16/88	13	22107	ALDRICH CHEMICAL CO., INC.	24.55	
		1	19,993-1 SODIUM AZIDE		
/16/88	13	22116	LANCASTER SYNTHESIS LTD	78.20	
		1	0619 15-CROWN-15 ETHER		
2/06/88	13	22108	MERCK & CO., INC.	292.55	
		1	MD-1095 DICHLOROACETIC ACID-D2		
2/27/88	13	22508	MATHESON GAS PRODUCTS	63.09	
		1	NO2 LECTURE BOTTLE, 99% PURITY, NO CHARGE FOR BOTTLE		

44-935-7237-30

Period: 07/01/1988-09/30/1992

Report Date: 16 Oct 92

Order: MAARTEN BUIJS

Comm. or rxn Date	Class	PO #	Vendor	Spent	Committed
5/01/89	12	24381	EXCITON	251.55	
		2	06200 KITON RED 620		
		2	06480 DODCI		
		5	20100 MALACHITE GREEN		
		1	AL002 AMMONYX LD		
5/23/89	12	24388	CVI LASER CORPORATION	1,670.47	
		1	B253-70 70R130T BEAMSPLITTER, 1" X 0.25", 45 DEGREE P-POL, 50 MW/CM-SQD, 10 MS, 10 HZ, FLAT + 2ND SURFACE AR COATING		
		7	Y2-1025- HIGH POWER LASER MIRRORS, 50 MW/CM-SQD, 10 MS, 10 HZ, FLAT		
		1	LWP(45)6 DICHROIC BEAMSPLITTER, 1" X 0.25", 45 DEGREE, P-POL, 50MW/CM-SQD, 10 MS, 10 HZ, FLAT + 2ND SURFACE AR COATING		
			Total EQUIPMENT	1,922.02	.00
6/01/89	13	24382	NEWPORT CORPORATION	4,636.80	
		8	TSX-1A BASIC TRANSLATION STAGE		
		3	ID-0.5 IRIS DIAPHRAGMS		
		3	MH-2P OPTIC INSERTS		
		1	RSX-1 COMPACT ROTATION STAGE		
		3	TSX-1B BASIC TRANSLATION STAGE		
		2	360-90 90 DEGREE MOUNTING BRACKET		
		1	910 SPATIAL FILTER		
		1	AC-2 ADJUSTABLE-RADIUS CHUCK, TIPS WITH BROAD V GROOVES FOR THICK OPTICS		
		1	LH2-T LENS HOLDER		
		1	LH-2 LENS MOUNT		
		9	LH1-T LENS HOLDER		
		9	LH-1 LENS MOUNT		
		2	600A-3 KINEMATIC OPTICAL MOUNT FOR 3" DIA OPTICS		
		3	RSA-2 COMPACT ROTATION STAGE		
		1	KPC043.A PLANO-CONCAVE LENS, FL -25 MM, + AR COATING		
		1	KPX187AR PLANO-CONVEX LENS, FL 100 MM		
		1	KPX118AR PLANO-CONVEX LENS, FL 500 MM		
		3	KPX079AR PLANO-CONVEX LENS, FL 38 MM		
		3	KPX088AR PLANO-CONVEX LENS, FL 76 MM		
		1	KPX094AR PLANO-CONVEX LENS, FL 100 MM		
		1	KPX076AR PLANO-CONVEX LENS, FL 25.4 MM		
6/21/89	13	24382	NEWPORT CORPORATION	96.00	
9/07/89	13	25549	SOMERVILLE LUMBER & SUPPLY	38.99	
		1	LUMBER & SUPPLIES NOT TO EXCEED \$100.00		
			Total SUPPLIES PRINT & STA	4,771.79	.00

Transaction Summary Report
44-935-7237-30
Period: 07/01/1988-09/30/1992
Report Date: 16 Oct 92

Order: PETER SAETA

mm. or xn Date	Class	PO #	Vendor	Spent	Committed
/19/89	12	24483	INMAC	469.41	
		25	MODEL 72 DATA CARTRIDGES		
			Total EQUIPMENT	469.41	.00
/01/88	47	23094	HARDWARE HOUSE INC	1,304.80	
		4	1 MBYTE, 100NS, LOW PROFILE SIMM		
/02/89	47	24484	MAC PRODUCTS USA	91.90	
		5	MAC+ TO IMAGEWRITER II, 8 PIN DIN TO 8 PIN DIN		
			Total COMPUTER EQUIPMENT	1,396.70	.00
Total for Orderer: PETER SAETA				1,866.11	.00

44-935-7237-30

Period: 07/01/1988-09/30/1992

Report Date: 16 Oct 92

Order: SHRENIK DELIWALA

Item, or Txn Date	Class	PO #	Vendor	Suient	Committed
5/01/91	12	32213	CVI-EAST	3,747.12	
		3	PTS3-073 FLAT MIRROR		
		1	PTS3-103 FLAT MIRROR		
		2	PTS3-103 FLAT MIRROR		
		2	PTS3-1037-10.5-.1M		
		1	SWP(10.5) 488-514T/780-840 R/ARSM 1037-.1M		
		1	SWP(10.5) 488-514T/780-840 R/ARSM 1037-.1M		
		1	PR 80-95 OUTPUT COUPLER		
		1	PR80-95- OUTPUT COUPLER		
		4	AR1-1037 FLAT MIRROR		
		1	PLCX-25. CONVEX LENS		
		1	AR1-1037 CONCAVE MIRROR		
3/26/91	12	34845	ESCO PRODUCTS	162.35	
		4	L520200 SF10 EQUILATERAL PRISMS, SIZE 20 MM		
3/26/91	12	34850	EDMUND SCIENTIFIC COMPANY	267.90	
		2	C43.493 SF18 EQUILATERAL PRISMS, 15MM X 15MM		
		2	C35.894 HIGH QUALITY RETRO REFLECTORS, APERATURE = 1" ACCURACY 5 SECONDS		
8/27/91	12	34846	CVI-EAST	222.48	
		1	BFT, 1" = 0.5MM, DIA 1" OPTIC AXIS LIES IN THE PLANE OF THE PLATE		
9/11/91	12	34850	EDMUND SCIENTIFIC COMPANY	170.00	
		2	C43.493 SF18 EQUILATERAL PRISMS, 15MM X 15MM		
		2	C35.894 HIGH QUALITY RETRO REFLECTORS, APERATURE = 1" ACCURACY 5 SECONDS		
1/06/91	12	35938	KLINGER SCIENTIFIC	2,205.00	
		7	338066 MR 50 LB TRANSLATION STAGE		
		2	338223 EQ 02 EXTERNAL BRACKET (EQ 5.02)		
		3	338 205B BASEPLATE Pba5s		
		1	133 102 P046 PRISM TABLE W/CLAMP		
		1	338 261 BRIDLES, BR3		
		1	080114 M.3 BY 6		
		1	080136 M.4 BY 6		
		1	080121 M.5 BY 8		
1/19/91	12	36087	ELECTROPHYSICS CORP	1,286.50	
		1	MODEL 72 IR ELECTROVIEWER		
		1	MODEL LP INFRARED LONG PASS FILTER		
		1	MODEL F2 FILTER HOLDER		
1/19/91	12	36088	EDMUND SCIENTIFIC COMPANY	22.90	
		1	C43.463 CONCAVE MIRROR OF FOCAL LENGTH 12MM, R 24MM, D 12MM		

44-935-7237-30

Period: 07/01/1988-09/30/1992

Report Date: 16 Oct 92

Orderer: SHRENIN DELIWALA

Comm. or rxn Date	Class	PO #	Vendor	Spent	Committed
2/02/91	12	36185	KLINGER SCIENTIFIC	2,819.54	
		4	133010 SL 25.4 MIRROR/BEAM SPLITTER MOUNTS, BD		
		4	133151 MOUNTING PLATE		
		4	338204B BASE PLATE #PB8 TO GO WITH SL25.4		
		4	338262 BR4 BRIDLES		
		4	080119 M4 12MM LONG SCREWS		
2/17/91	12	36254	EG&G ELECTRO-OPTICS	675.00	
		1	RL1024DA STANDARD UNTAPPED 1024 PIXEL D SERIES		
		1	RC0730LN EVALUATION BOARD		
01/07/92	12	36191	NATIONAL INSTRUMENTS	1,356.25	
		1	776305-0 NB-DMA2800 COMPUTER, NI 488.2 DRIVER & SOFTWARE		
01/17/92	12	36826	NEWPORT CORPORATION	548.75	
		1	LF05B SEE CAT#		
		2	F-1RC1 INFRARED SENSOR CARD		
02/11/92	12	36682	WALL INDUSTRIES INC	131.88	
		2	W5S1000B 5V DC, 1 AMP		
		2	W15S500B 15V DC, 500MA		
		2	W12D500B +/- 12V DC, 500 MA		
02/11/92	12	36682	WALL INDUSTRIES INC	222.54	
			Total EQUIPMENT	13,838.21	.00
02/05/90	13	27353	SICKLES DISTRIBUTION SALES	242.90	
		4	DPD201 AMPLIFIER		
		4	GPD202 AMPLIFIER		
			Total SUPPLIES PRINT & STA	242.90	.00
12/06/89	72	26606	LASER SCIENCE	200.00	
		1	REPAIR OF HANS GREEN EISEN CO2 LASER		
			Total EQUIPMENT REPAIRS/MAINT	200.00	.00
Total for Orderer: SHRENIN DELIWALA				14,281.11	.00

ATTACHMENT I: Equipment Purchases
Transaction Summary Report
44-935-7237-30
Period: 07/01/1988-09/30/1992
Report Date: 16 Oct 92

Orderer: WALTER MIEHER

Comm. or Trxn Date	Class	PO #	Vendor	Suent	Committed
01/14/92	12	36903	OMICRON ASSOCIATES	15,661.20	
		1	LEED/AUGER SYSTEM INCLUDING: SPECTALEED ELECTRON OPTICS SYSTEM LEED POWER SUPPLY, MODEL NGL10 AUGER ELECTRON GUN POWER SUPPLY, MODEL NGE35 AUGER RAMP GENERATOR, MODEL RGL20 AUGER UNIT, MODEL MUL CABLES, MANUALS		
			REFERENCE OMICRON QUOTE #R0109PHS-2 @ \$35,605.00 LESS NSF FYI 12% DISCOUNT ELECTRICAL CONNECTION MODIFICATION		
03/13/92	12	36902	UTI	12,500.00	
		1	QUADRUPOLE MASS SPECTROMETER SYSTEM INCLUDING UTI 100C-30 MASS ANALYZER, MODEL 03910-iiii CABLE, PART #05168-0010 RF/PROBE CABLE, PART #05185 @ \$14,500.00 LESS \$2,000.00 UNIV DISCOUNT		
08/07/92	12	36903	OMICRON ASSOCIATES	10,144.27	
		1	LEED/AUGER SYSTEM INCLUDING: SPECTALEED ELECTRON OPTICS SYSTEM LEED POWER SUPPLY, MODEL NGL10 AUGER ELECTRON GUN POWER SUPPLY, MODEL NGE35 AUGER RAMP GENERATOR, MODEL RGL20 AUGER UNIT, MODEL MUL CABLES, MANUALS		
			REFERENCE OMICKON QUOTE #R0109PHS-2 @ \$35,605.00 LESS NSF FYI 12% DISCOUNT ELECTRICAL CONNECTION MODIFICATION		
			Total EQUIPMENT	38,305.47	.00
Total for Orderer: WALTER MIEHER				38,305.47	.00